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Case Report

UNDERSTANDING THE SENSITIVITY, SPECIFICITY, AND PREDICTIVE VALUES USED IN DIAGNOSTIC TESTS

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ABSTRACT

Diagnostics and screening tests have been routinely used for screening diseased or infected from healthy and normal individuals. Clinicians rely on diagnostic and screening test results to make decisions on the diagnosis and initiate the treatment. However, the diagnostic test outcomes vary from different test procedures. The outcomes are not always 100% accurate. Hence, the tests showing more accuracy and high sensitivity and specificity are given high preference by the clinicians. To evaluate the performance of dichotomous binary outcomes obtained from diagnostic test results, several statistical measures have been routinely used. They are accuracy, sensitivity, specificity, positive predictive value, and negative predictive values and are intimately connected with the concept of probability. Very often interpreting the outcome of false positives and true negatives is quite intuitive, but several students and even health professionals have difficulties in assessing the associated probabilities. Hence, in this article, we have explained the terms and the statistical measures in an easy manner with examples and also how to relate and interpret them in a diagnostic test.

Keywords: Diagnostic, probabilities.

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INTRODUCTION

Clinicians handle various cases daily with different levels of severity in a hospital environment and they have to rely on the number of clinical laboratory tests and imaging results to make decisions on the diagnosis and manage treatments [1-5]. Diagnosis test procedures include different kinds of evidence, such as medical tests (blood tests, X-rays, magnetic resonance angiography), medical signs (clubbing of the fingers, a sign of lung disease), or symptoms (pain in a particular pattern). In clinical practice, it is essential to correctly identify the diagnostic tests that are useful to a specific patient with a specific condition [4-6]. Diagnostic tests result with the least error and the most accuracy is more desirable in a treatment. An accurate and timely diagnosis with the smallest probability of misdiagnosis, missed diagnosis, or delayed diagnosis is crucial in the management of any disease [1,2]. The inaccurate diagnostic results burden the individuals with unnecessary treatments and harm normal individuals [3]. Although diagnostic testing is often a vital factor in medical decision-making, testing may have unnecessary or unintended consequences.

The power of a test to distinct patients from healthy individuals determines their accuracy and diagnostic value. Hence, a test procedure with 100% accuracy is considered and given first preference. In reality, this does not happen always because the accuracy of a test varies for various diseases and in different circumstances. Most of the diagnostic laboratory test results are inaccurate and might erroneously recognize some healthy and normal individuals as diseased or infected individuals (a false positive [FP]) or might erroneously recognize some affected or infected individuals as disease-free individuals (a false negative [FN]). In addition to the risk of providing incorrect information, it also delays the start of treatment or brings unnecessary treatment to healthy normal individuals. Diagnostic test procedures require considerable resources and time and may have adverse effects for example pneumothorax caused by lung biopsy or may prompt additional screening procedures.

There has been a growing interest in developing rapid diagnostic test (RDT) kits for plasmodium species detection over the past few decades. At present, three antigens *Plasmodium falciparum* histidine-rich protein 2 (HRP2), plasmodial aldolase, and plasmodial lactate dehydrogenase have been used for rapid diagnosis. Tests targeting HRP2 contribute to more than 90% of the malaria RDTs in the current use. However, the specificities, sensitivities, numbers of FPs, and numbers of FNs tests vary considerably, illustrating the difficulties and challenges facing current RDTs. The characteristics of a test that reflects the aforementioned abilities are accuracy, sensitivity, specificity, and positive and negative predictive values (NPV) [4-6]. In this article, we explain the concept of diagnostic tests and their statistical measures, such as accuracy, sensitivity, and specificity with illustrated examples.

In this article, the following explanation will be used for the diagnostic terms.

True positives (TP) = the number of individuals accurately diagnosed as infected individuals. In other words, in reality, the subject has a condition (disease or infection) and the diagnostic test results also show positive results (disease or infection).

FP = the number of individuals inaccurately diagnosed as infected individuals. In other words, in reality, the individuals were neither infected nor had the disease condition (normal and healthy), and the diagnostic test results showed positive results (disease or infection).

True negatives (TN) = the number of individuals accurately diagnosed as healthy and normal individuals. In other words, in reality, the individuals who do not have disease or infection and the diagnostic test results show negative results (normal and healthy).

FN = the number of individuals inaccurately diagnosed as healthy and normal individuals. In other words, in reality, the individuals who have the disease or infection and the diagnostic test results show negative results (normal and healthy).

Accuracy

The accuracy of a diagnostic test depends on how best it can discriminate the infected and normal healthy individuals properly. The numerical value of accuracy represents the proportion of TP results

(both TP and TN) in the selected population. An accuracy value of 99% means that 99% of the time the test result is accurate, regardless positive or negative. To evaluate the accuracy of a diagnostic test, we need to calculate the proportion of TPs and TNs in all cases under screening. Statistically, this can be presented as:

Accuracy =	(True Positives+True Negatives)
	(True Positives+True Negatives+False Positives+False Negatives)

Sensitivity

The sensitivity of a diagnostic test depends on how best it can detect the diseased or infected individuals accurately. Sensitivity is the likelihood of a positive test result in cases with disease or infection (TP). The sensitivity shows how good the screening test is at detecting a diseased individual. The sensitivity numerical values reflect the probability that a diagnostic test can recognize patients who have the disease. The higher the sensitivity numerical value, the less likely the diagnostic test will yield false-positive results. For example, if a sensitivity value of 99% indicates that when we conduct a diagnostic test on a person with a certain disease, there is a 99% probability that this disease-free individual will be identified as positive. A high-sensitivity screening test aims to consider all possible positive outcomes without excluding anyone with a disease or illness. Therefore, a test with high sensitivity is often used for disease screening. To evaluate the sensitivity of a particular diagnostic test, we need to calculate the proportion of TPs in diseased or infected individuals. Statistically, this can be presented as:

$$\text{Sensitivity} = \frac{\text{True Positives}}{(\text{True Positives} + \text{False Negatives})}$$

For example, a diagnostic test that is positive in 8 out of 10 individuals with a disease or infection has a sensitivity of 0.8 and this can be expressed as 80% sensitivity. A diagnostic test with a low sensitivity value does not identify many screened individuals with disease or infection.

Specificity

The specificity of a diagnostic test depends on the ability to accurately detect healthy and normal individuals. Specificity is the likelihood of a negative test result in patients without disease or infection (true-negative). It suggests how good the test is at identifying normal and healthy individuals. The numerical value of specificity represents the likelihood that a test can identify a specific disease without giving false-positive results. For example, if a test's specificity is 99%, it means that if we perform a diagnostic or screening test on a patient without a certain disease, there is a 99% chance that this patient will be identified as negative. A good screening or diagnostic test should have both high sensitivity and specificity. To evaluate the specificity of a particular diagnostic test, we need to calculate the proportion of TNs among the healthy and normal individuals. Statistically, this can be presented as:

$$\text{Specificity} = \frac{\text{True Negatives}}{(\text{True Negatives} + \text{False Positives})}$$

For example, a diagnostic test showing negative in 9 out of 10 individuals without disease has a specificity of 0.9 and this can be expressed as 90% specificity. Specificity denotes how well a test accurately detects individuals with disease because tests with high specificity have a low FP.

Positive predictive value (PPV)

PPV and NPV are best considered as the clinical relevance of a diagnostic test. The PPV is the probability that those who have positive diagnostic test results truly have the condition (disease or infection), and the NPV is the probability that those who have negative test results are without the condition (normal and healthy). The PPV will explain the probability that a subject who has been diagnosed with positive results will have a disease. The NPV will explain the probability that a subject who has been diagnosed with negative results will not have the disease.

$$\text{Positive predictive value } (\text{PPV}) = \frac{\text{True Positive}}{(\text{True Positive} + \text{False Negative})}$$

NPV

$$\text{Negative predictive value } (\text{NPV}) = \frac{\text{True Negative}}{(\text{True Negative} + \text{False Positive})}$$

CASE STUDY 1

Assume that, we have a sample of 100 individuals, of which 50 are normal and healthy individuals and 50 are with disease or infection. This shows that 50% of the individuals are diseased or infected. The prevalence of the disease is 50%. If a diagnostic test shows positive results for all the infected or diseased individuals and negative results for the rest of the healthy and normal individuals, then the test is considered as 100% accurate. Using the aforementioned formula, the sensitivity, specificity, PPV, and NPV can be determined. In this case study, the TP is 50 individuals and the TN is 50 individuals.

$$\text{Accuracy} = \frac{50+0}{(50+0+50+0)} \times 100 = 100\%$$

$$\text{Sensitivity} = \frac{50}{(50+0)} \times 100 = 100\%$$

$$\text{Specificity} = \frac{50}{(50+0)} \times 100 = 100\%$$

$$\text{Positive predictive value} = \frac{50}{(50+0)} \times 100 = 100\%$$

$$\text{Negative predictive value} = \frac{50}{(50+0)} \times 100 = 100\%$$

The sensitivity of the test is 50 divided by 50 or 100% and its specificity in determining healthy and normal people is 50 divided by 50 or 100%. The positive and NPV also for this case study are 100%. This test is ideal for both screening and final diagnosis of a disease, considering the statistical characteristics described above.

CASE STUDY 2

Assume that, we have a sample of 100 individuals, of which 50 are normal and healthy individuals and 50 are with disease or infection. The prevalence of the disease is 50%. If the diagnostic test can only diagnose 25 out of the 50 diseased or infected individuals and the remaining individuals are stated as normal and healthy. Using the formulae sensitivity, specificity, PPV, and NPV can be determined.

$$\text{Accuracy} = \frac{25+50}{(25+0+25+50)} \times 100 = 75\%$$

$$\text{Sensitivity} = \frac{25}{(25+25)} \times 100 = 50\%$$

$$\text{Specificity} = \frac{50}{(50+0)} \times 100 = 100\%$$

Table 1: Terms used to explain the sensitivity, specificity, and accuracy

Outcome of the diagnostic test	In reality, the condition of the individuals		
	Positive	**Negative**	**Row total**
Positive	True positives (TP)	False positives (FP)	TP+FP (total number of individuals diagnosed with positive test results
Negative	False negatives (FN)	True negatives (TN)	FN+TN (total number of individuals diagnosed with negative test results
Column total	TP+FN (in reality, the total number of individuals having the disease or infection)	FP+TN (in reality, the total number of individuals not having the disease or infection)	N=TP+TN+FP+FN (total number of individuals screened in the study)

Table 2: Calculations showing the sensitivity, specificity, and accuracy

Outcome of the diagnostic test	In reality condition of individuals (diseased/infected)		
	Positive	**Negative**	**Row total**
Positive	50 (TP)	0 (FP)	50 (TP+FP)
Negative	0 (FN)	50 (TN)	50 (FN+TN)
Column total	50 (TP+FN)	50 (FP+TN)	100 N=TP+TN+FP+FN

FP: False positive, TP: True positives, FN: False negative, TN: True negatives

Table 3: Calculations showing the sensitivity, specificity, and accuracy

The outcome of the diagnostic test	In reality condition of individuals (diseased/infected)		
	Positive	**Negative**	**Row total**
Positive	25 (TP)	0 (FP)	25 (TP+FP)
Negative	25 (FN)	50 (TN)	75 (FN+TN)
Column total	50 (TP+FN)	50 (FP+TN)	100 N=TP+TN+FP+FN

Table 4: Calculations showing the sensitivity, specificity, and accuracy

Outcome of the diagnostic test	In reality condition of individuals (diseased/infected)		
	Positive	**Negative**	**Row total**
Positive	50 (TP)	25 (FP)	75 (TP+FP)
Negative	0 (FN)	25 (TN)	25 (FN+TN)
Column total	50 (TP+FN)	50 (FP+TN)	100 N=TP+TN+FP+FN

$$\text{Positive predictive value} = \frac{25}{(25+0)} \times 100 = 100\%$$

$$\text{Negative predictive value} = \frac{50}{(50+25)} \times 100 = 66.66\%$$

Of the 100 cases that have been tested, the test has only determined 25 diseased individuals and 50 healthy individuals correctly. Hence, the accuracy of the test is equal to 75 divided by 100 or 75%. The sensitivity is calculated from the 50 diseased individuals, and the test has only diagnosed 25. Therefore, its sensitivity is 25 divided by 50 or 50%. The specificity is calculated from the 50 healthy normal individuals, and the test has correctly identified all the 50 healthy normal individuals. Thus, its specificity is 50 divided by 50 or 100%. Regarding the PPV, there is a 100% probability; the diagnosed individuals will have the disease. There is a 66.66% probability that the diagnosed individuals are estimated to be disease free.

CASE STUDY 3

Assume that, we have a sample of 100 individuals, of which 50 are normal and healthy individuals and 50 are with disease or infection. The prevalence of the disease is 50%. This time we will assume that the test has been able to identify 25 of the 50 healthy individuals and has reported the remaining individuals as diseased or infected. Using the formulae, sensitivity, specificity, PPV, and NPV can be determined.

$$\text{Accuracy} = \frac{25+50}{(25+0+25+50)} \times 100 = 75\%$$

$$\text{Sensitivity} = \frac{50}{(25+25)} \times 100 = 100\%$$

$$\text{Specificity} = \frac{25}{(50+0)} \times 100 = 50\%$$

$$\text{Positive predictive value} = \frac{50}{(50+25)} \times 100 = 66.66\%$$

$$\text{Negative predictive value} = \frac{25}{(25+0)} \times 100 = 100\%$$

Of the 100 individuals examined, 25 healthy individuals and 50 diseased individuals were correctly detected in the diagnostic test. Therefore, the accuracy of the test is equal to 75 divided by 100 or 75%. From the 50 diseased individuals, the test has diagnosed all the 50 diseased individuals. Thus, the sensitivity of the test is 50 divided by 50 or 100%. From the 50 healthy normal individuals, the test correctly detected only 25 healthy individuals. Therefore, the specificity of the test is 25 divided by 50 or 50%. Regarding the PPV, there is a 66.66% probability; the diagnosed individuals will have the disease. There is a 100% probability that the diagnosed individuals are estimated to be without disease.

AUTHORS' CONTRIBUTIONS

Dr. Umasankar: Inception of the idea and preparation manuscript; Dr. Kasi Marimuthu: Inception of the idea and writing the manuscript, and preparation of the manuscript, Dr. Nagadharshan Devendra: Involved in the preparation of the manuscript.

CONFLICTS OF INTEREST

No conflicts of interest are present.

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